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THE INFLUENCE OF HEATING OF LOW PRESSURE GAS IN A SHOCK TUBE ON THE INCREASE OF THE ATTAINABLE STAGNATION TEMPERATURE

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

THE INFLUENCE OF HEATING OF LOW PRESSURE GAS IN A SHOCK TUBE ON THE INCREASE OF THE ATTAINABLE STAGNATION TEMPERATURE

G. L. Grodzovskiy

The problem of increase of the attainable stagnation temperature of the gas flow in a shock tube is investigated. It is shown that for this purpose the heating of low pressure gas is advisable. There is analyzed the effect of heating of low pressure gas on the increase of the attainable stagnation temperature in flow behind the shock wave for the case of a single-diaphragm cylindrical shock tube.

To the gas-dynamics of flows in shock tubes there is dedicated a large number of investigations (see, for example, [1]-[3]). The main attention in these investigations is given to the problem of attaining the maximum ratio of the shock wave velocity U to the speed of sound in stationary gas in front of the wave a_1:

$$M_1 = \frac{U}{a_1}.$$

where $a_1 = \sqrt{\varkappa_1 g R_1 T_1}$.

T_1 - static temperature of low-pressure gas before the wave,

$\varkappa_1$ and R_1 - adiabatic index and gas constant of this gas.

For the simplest cylindrical single-diaphragm shock tube

(Fig. 1) the maximum value of number M_1, as is known, is attained with infinite pressure drop on the diaphragm:

$$M_{1\,max} = \frac{(\varkappa_4+1)a_4}{(\varkappa_4-1)a_1} = \frac{\varkappa_4+1}{\varkappa_4-1}\sqrt{\frac{\varkappa_4 R_4 T_4}{\varkappa_1 R_1 T_1}}, \qquad (1)$$

where subscript 4 notes the parameters of high pressure gas.

In accordance with relationship (1) the number M_1 grows with increase of the temperature of high-pressure gas T_4 and with increase of its gas constant R_4. Therefore much attention in [1], [3] is given to the problems of heating high-pressure gas with the use of high-temperature gases with low molecular weight. From these positions the low-pressure gas (T_1) was considered cold.

We investigated the problem of increase of the attainable stagnation temperature T_0 of gas flow in the shock tube. It is shown that for this purpose the heating of low-pressure gas is advisable. This effect was independently found earlier by N. I. Khvostov by calculation for finite pressure drops on the diaphragm. Below on the basis of analytical solution there is obtained the universal dependence of the attainable stagnation temperature of gas flow in the shock tube on the degree of heating of low-pressure gas.

Let us conduct analysis for the simplest scheme of shock tube for ideal gases (see Fig. 1). The obtained results can be spread to the cases of more complex schemes and for gases.

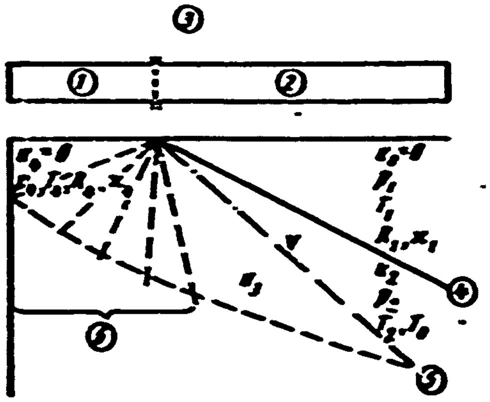

Fig. 1. 1 - high-pressure chamber; 2 - low-pressure chamber; 3 - diaphragm; 4 - shock wave; 5 - contact surface; 6 - centered rarefaction wave.

The stagnation temperature T_0 of gas flow in region 2 (behind the shock wave), naturally, depends on the flow velocity $u_2 = u_3 = V$ and parameters of low-pressure gas. The limiting value of gas flow velocity V is achieved with infinitely large pressure drop on the diaphragm, the value of V_{max} depends only on the parameters of high-pressure gas:

$$V_{max} = \frac{2}{\varkappa_4 - 1} a_4 = \frac{2}{\varkappa_4 - 1} \sqrt{\varkappa_4 g R_4 T_4}. \tag{2}$$

For fixed value of V we come to the problem of maximum attainable stagnation temperature T_0 in the flow behind the shock wave in gas, compressed by a piston moving at speed V (the contact surface plays the role of piston, see Fig. 1).

From equations of propagation of the shock wave it is possible to obtain the following expression for the relative flow velocity behind the shock wave:

$$\frac{V}{a_1} = \frac{V}{\sqrt{\varkappa_1 g R_1 T_1}} = M_1 \left[1 - \frac{2\left(1 + \frac{\varkappa_1 - 1}{2} M_1^2\right)}{(\varkappa_1 + 1) M_1^2}\right] = \Phi(M_1). \tag{3}$$

The gradient of static temperatures T_2/T_1 on the shock wave is determined by known relationship

$$\frac{T_2}{T_1} = \frac{\left(\varkappa_1 M_1^2 - \frac{\varkappa_1 - 1}{2}\right)\left(\frac{\varkappa_1 - 1}{2} M_1^2 + 1\right)}{\left(\frac{\varkappa_1 + 1}{2}\right)^2 M_1^2} = f(M_1). \tag{4}$$

Accordingly the ratio of the sought stagnation temperature T_0 in the flow behind the shock wave to the static temperature of low-pressure gas T_1 can be written in the form

$$\frac{T_0}{T_1} = f(M_1) + \frac{\varkappa_1 - 1}{2} \Phi^2(M_1). \tag{5}$$

whence follows the expression for the dimensionless value of stagnation temperature in the flow behind the shock wave

$$\bar{T}_0 = \frac{T_0}{V^2/(\varkappa_1 g R_1)} = \frac{f(M_1)}{\Phi^2(M_1)} + \frac{\varkappa_1 - 1}{2}. \tag{6}$$

One should consider that according to equation (3) to each value of parameter M_1 there corresponds a certain value of relative flow velocity behind the shock wave (speed of piston) V/a_1.

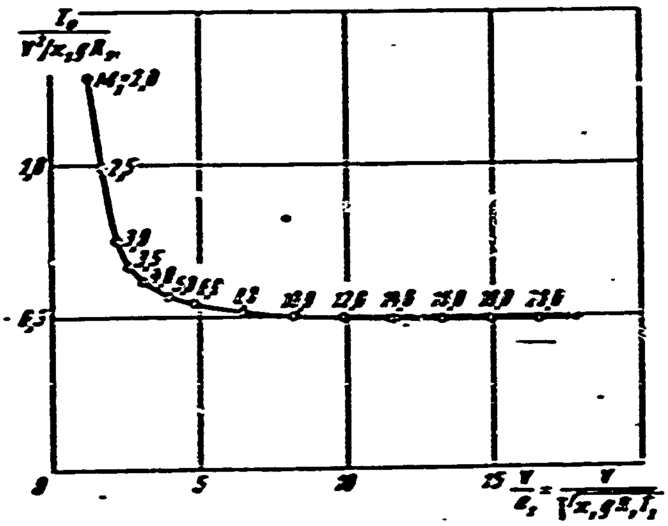

Fig. 2.

Figure 2 shows the change of the dimensionless value of stagnation temperature $\overline{T}_0$ depending on the relative velocity V/a_1. It is evident that with assigned value of flow velocity V behind the shock wave (speed of piston), increase of the temperature of low-pressure gas T_1, leads to increase of the attainable stagnation temperature T_0. So, for example, if parameter M_1 was in the range $10 \leq M_1 \leq 20$, then with heating of low-pressure gas in the shock tube it is possible to raise the stagnation temperature T_0 in the flow behind the shock wave by more than twice.

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